Communications System Architecture Development
For
Air Traffic Management & Aviation Weather Information Dissemination

Research Task Order 24

Subtask 4.11, Identify Communications Systems and Technology Gaps

(Task 10.0)

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Table of Contents

Table of Figures

Table of Tables

1 Introduction

1.1 Overview

This report identifies communications technology gaps resulting from an analysis of the recommended 2007 and 2015 Communication System Architecture (CSA). The gaps reflect the communications systems, data links and components that are not addressed by present and near term development programs. The gaps are presented in sufficient detail to enable consideration of technical solutions.

This report follows Task 8, which presented a transition plan for achievement of the 2015 AATT communications architecture as defined in Task 5. The transition plan will highlight the key milestones and interdependencies that are necessary to achieve this goal.

1.2 Approach

To meet the task objective, the communications technology gaps are summarized and categorized as system or component gaps and further identified according to the associated air, ground, and/or space platform.

1.3 Terms and Definitions

The following terms and definitions provide the framework for identifying and categorizing the gaps (Task 10) and candidate solutions (Task 11).

1.3.1 System Gaps

System gaps are concerned with the collection, processing, and distribution of information necessary for safe and efficient operations within the NAS. System gaps fall under one of three categories defined below:

- New systems: An entirely new method of collecting, processing, and distributing data is required to meet the new requirements of the proposed 2015 Communications System Architecture.
- New or improved data link: The protocols and hardware necessary to distribute data through the network are inadequate for the expanded requirements and need improvement.
- Improved network: The protocols are adequate for the expanded requirements; however, the physical configuration (number and location of network nodes) can be improved to provide improved access, response time, and availability.

1.3.2 Component Gap

Component gaps are specified at the following level (applicable to air, ground, and space platforms):

- Radio Frequency (RF) Technology (receivers, transmitters, RF converters, etc.): The hardware that enables wireless transmissions between nodes in such a manner that it may be transmitted and received via antenna technology.

- Antenna Technology: The hardware by which a node in the network receives and transmits RF signals.
- Network/switching and routing technology: The software used to connect the various network nodes and ensure that information is properly routed to the correct destination.

1.4 Relationship to Other Tasks

Task 10 is based on the summary and conclusions drawn from the recommended AATT and AWIN Communications System Architectures (CSA). The purpose of the document is to present a clear picture of the technological gaps in the current or planned communications systems and components. These gaps must be addressed to meet the projected requirements for the 2007 and 2015 CSA. For this purpose, we identify the basic building blocks of a system or component that will form the required communications infrastructure. Such systems or components, if targeted for future research and development (see Task 11), will reduce the implementation risk for the aeronautical industry and facilitate efficient and effective aeronautical communication. Figure 1.4-1 Task Relationship shows the relationship of Task 10 to the other Advanced Air Transportation Technologies (AATT) TO24 Tasks.

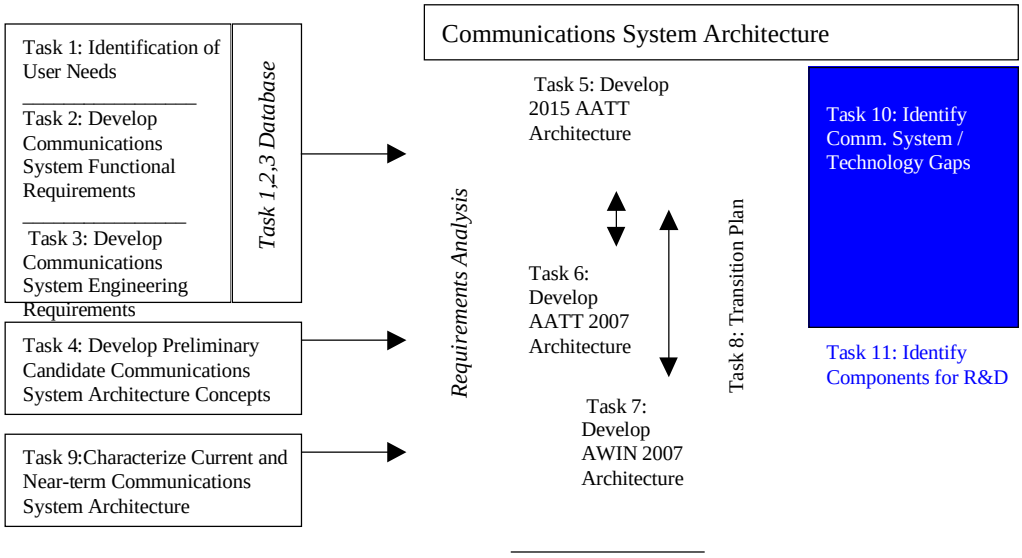

Figure 1.4-1. Task Relationship

2 Gap Identification

Figure 2-1 shows the conceptual communications architecture for 2015. The shaded areas represent the communications system technology gap areas addressed in this report. The ground segment gaps include the interface to the NAS-Wide Information System (NWIS) and to commercial passenger services. It is believed that this is the area where standards for data, security and inter-network (ATN/Non-ATN) communications are needed. In addition, the interface between commercial service providers and the FAA systems will require selection and agreement in national and international forums (i.e. - ICAO) on numerous communications-related standards and performance metrics. In the air segment, shown on the right of the chart, the avionics must support multiple communications links, high-speed data rates and communications between various data communications processors and displays. In the space segment (indicated by the satellite icon), it is assumed that commercial service providers will have the satellites in place, by 2007, to offer broadcast services to airspace users via Ka-band. The gaps include the availability of suitable antennas and receivers for all classes of aircraft that resolve the problems associated with rain attenuation, weight, flexibility and end-user cost. Gaps in the architecture will result in a subset of user needs not being appropriately addressed.

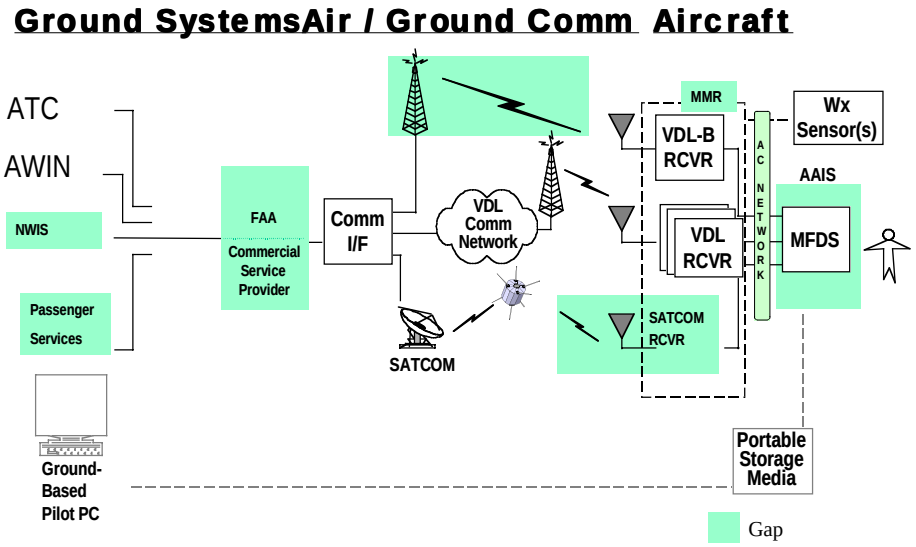

Figure 2-1. 2015 Communications Architecture

2.1 Service Provisions Concepts vs Communication Architectures

The process of defining the 2015 AATT and 2007 AATT and AWIN architectures discussed in Tasks 5-7 involved an analysis of the operational concepts versus the infrastructure provided to support those concepts. To do this, a list of services (concept enablers) along with their supporting functions and associated message types was used as the basis for evaluation for each of the possible communications link alternatives. The resulting recommendations are based on the premise that the technology already exists in the current NAS environment, is planned, or is technically feasible for the timeframe considered. The gap analysis identifies the communications system and or components that are not in the current NAS plan, but must be in place to support our recommended architecture. If the technology is targeted for 2007, it must be demonstrable by 2003.

The services discussed above have been consolidated into nine technical concepts each with distinct communications requirements. The nine technical concepts are listed below along with the related communications gap areas. The entries on the table below are as follows:

- "Required": indicates that the gap must be addressed to adequately meet the objectives of the associated technical concept
- "Useful": indicates that improvements in these areas are not required to meet the technical concept but are useful to achieve the service objective in an efficient manner.

In addition to these communications technology system and component gaps, we have identified several crosscutting issues that will impact data distribution in the NAS including common data definitions and interfaces for the NAS Wide Information System (NWIS), and information security.

Table 2.1-1. Communications Technology Gaps Related to NAS Service Technological Concepts

ID	Service Description	Technical Concept	Gap Areas and Solution Alternatives		
			A. Advanced Aircraft Information System	B. VHF Improvements	C. SATCOM
1	Aircraft continually receive Flight Information to enable common situational awareness	Flight Information Service	Required	Useful	Required
2	Aircraft continuously receive Traffic Information to enable common situational awareness	Traffic Information Service	Required	Useful	Required
3	Controller - Pilot voice communication	Controller-pilot communication (voice)	Useful	Useful	
4	Controller - Pilot messaging supports efficient Clearances, Flight Plan Modifications, and Advisories (including Hazardous Weather Alerts)	Controller-Pilot Data Link Communications (data)	Useful	Useful	
5	Aircraft exchange performance / preference data with ATC to optimize decision support	Decision Support	Useful	Useful	Useful
6	Aircraft continuously broadcast data on their position and intent to enable optimum maneuvering	ADS Reporting	Useful		
7	Pilot - AOC messaging supports efficient air carrier/air transport operations and maintenance	AOC	Useful		
8	Aircraft report airborne weather data to improve weather nowcasting/forecasting	Weather Reporting	Useful		
9	Commercial service providers supply in-flight television, radio, telephone, entertainment, and internet service	Passenger Service	Required		Required

2.2 Communications Technological Gaps

Analysis of the communications system gaps includes the identification of user needs that will not adequately be met. User needs, in this context, encompass the requirements of all NAS airspace users (ATC, aircrew, AOC and other service providers). In Task 1 and 2 of this RTO, user needs and functional communications requirements were collected from various FAA and industry documents. These requirements are contained in the User Requirements Database submitted as a Task 1, 2, 3 Deliverable. The user needs included in the gap summary below are representative of user requirements that will not adequately be met if action is not taken to fill the gaps detailed in this report. The solution candidates are summarized in this section and presented in greater detail in Task 11.

2.2.1 Aircraft Communications Network Gap

With more data being sent to the cockpit, an aircraft network similar to ground local area networks will be needed. Higher data rates, increasing exchanges between on-board processors, and the combined need for high reliability and ease of installation drive the need for an aircraft network. This section focuses on the need for development of the Advanced Aircraft Information System (AAIS) consisting of high speed network (Flight Deck/Cabin), airborne server, multifunctional displays, and intelligent router. This is considered a communications technology system gap because it is not addressed in the current NAS plan but is an integral part of the recommended AATT 2015 Architecture as well as the 2007 AATT and AWIN Architectures.

Fusion of data, use of common symbology, and other techniques are needed to support heads-up and situational awareness requirements for the pilot. With present technology, the integration and installation of displays in GA airplanes is expensive. New technologies that allow affordable installations in small cockpits are necessary.

User Needs Impacted:

- Graphical weather to the cockpit
- Common situational awareness
- Self separation
- Ability to display, in the cockpit, real-time weather and surrounding traffic
- Capability to support the use of graphical weather products and aeronautical information in accordance with the RTCA MOPS
- Data link control and display units integrated in the cockpit within, easy reach and forward field of view of the aircrew
- Data link message formatting function that ensures that the sender's message and intent is fully and accurately represented on the receiver's display.

Summary of Solution Candidates:

Advanced Aircraft Information System (AAIS)

AAIS will aid the exchange of information by providing a standard and uniform communication media for data transmission. Otherwise, numerous custom interfaces will be needed, adding to aircraft complexity and cost. The proposed solution candidates are discussed in further detail in Task 11.

- The aircraft avionics subsystems, including the communication components, should be networked using high-speed Commercial Off-the-Shelf (COTS) hardware and software.
- COTS technologies for high-speed digital data transfer applicable to terrestrial LANs should be adapted for use in the airborne environment.
- COTS technologies for multi-protocol routers applicable to terrestrial LANs should be adapted for use in the airborne environment.
- COTS technologies for servers applicable to terrestrial LANs should be adapted for use in the airborne environment.
- Development of low-cost displays for the following applications:
  - Airborne Collision Avoidance System (ACAS) symbology
  - Taxi symbology generated from data transmitted by airport ground traffic control
  - Heads-up symbology with uplinked taxi directions
  - Information fusion on pilot's tactical displays
  - Fusion of information (terrain, tower obstacles, and proximate aircraft) techniques applicable to commercial airplanes should be examined.
- Development of high quality voice synthesis technology should be pursued for CPDLC message applications.

2.2.2 VHF Communications Gaps

Increasing the capacity of the VHF band will support two-way services and will help ease the transition to higher data exchanges proposed for the satellite broadcast solution. Improvements in the antenna design, modulation schemes, compression techniques, voice over data and voice synthesis technologies will allow for more efficient transmission of data.

2.2.2.1 Directional VHF Antenna

Multiple VHF links are expected for future aircraft including combinations of 25 kHz DSB-AM voice, ACARS, VDL Mode 2, and VDL Mode 3. Installing multiple systems on large aircraft is difficult but usually manageable. Installation of multiple systems on small aircraft is more difficult due to the limited space available and may increase interference between systems. Reducing interference typically requires frequency separation, which consequently reduces the spectrum available for use.

2.2.2.2 Modulation

The optimum modulation for large FIS broadcast messages has not been condsidered. The D8PSK modulation scheme selected by ICAO for VDL Mode 2 and VDL Mode 3 was based on the existing 25 kHz spacing in the VHF band, relatively short messages, and two-way communications. Modulation schemes considered were Differential Eight-Phase Shift Keying (D8PSK), Eight-Level Frequency Modulation (8LFM), 4-ary Quadrature Amplitude Modulation (4QAM), and 16-ary QAM (16QAM). ICAO working paper AMCP/WG-C/5 summarized the modulation analysis as follows:

- 4QAM has insufficient throughput and was primarily considered to improve range and fading performance
- 16QAM is the most complex scheme and is significantly more costly than the others. It has a less certain performance at longer ranges and under fading conditions.
- 8LFM with a nonlinear transmitter that can provide more RF power on the channel and provides more margin than D8PSK
- D8PSK has greatly superior Adjacent Channel Interference (ACI) performance for digital modulation against digital (mode 2/ mode 3) and
- provides a channel data rate of 31.5 kb/s with a baud rate of 10.5 kbaud and three bits per symbol.

The detailed discussion indicated that 16QAM could yield a throughput of 37.8 kb/s for longer (1024 octet) messages based on a 25 kHz bandwidth. FIS and other services using large message sizes could benefit from the greater throughput.

If the VHF band and 25kHz constraints for FIS-B are changed, a more efficient modulation scheme may be possible and appropriate. Possible changes include: 1) Increase the 25 kHz bandwidth, 2) Assign FIS to another band besides VHF, 3) Revise the modulation analysis based on broadcast only transmission.

Virtual Network

The current spectrum allocation is not optimized for digital communication. As discussed in detail in Task 11, an automated channel assignment or virtual channel concept would allow more efficient use of the VHF spectrum. Instead of assigning frequencies on a sector basis, automatic message routing to aircraft would be done by the ground network, relieving the controller and pilot of frequent tuning and also optimizing the use of frequencies.

2.2.2.3 Compression

Compression has not been considered for all of the data types identified for aeronautical communications. As further discussed in Task 11, compression techniques can reduce the volume of data required for transmission, increasing the capacity of the data link. Compression is independent of the link and can be applied equally to the VHF band or the SATCOM band.

User Needs Impacted:

- Delivery of FIS
- Delivery of two-way ATC-Pilot communications.

Summary of Solution Candidates:

The following solution candidates are discussed in more detail in Task 11.

1. Efficient modulation schemes will allow more data over limited channel
2. Onboard processing could allow weather images to be reduced to aggregate measurements without the need to send the entire image. New compression schemes (Wavelet, Fractal, Principal Component Analysis (PCA) would increase the available bandwidth of current transmission links.
3. Automated channel assignment (roaming). Transparent change of frequency could optimize frequency layout.
4. Vocoder standards should be adopted to ensure global interoperability and high quality.
    - Compatibility of NEXCOM Vocoders with Commercial satellite service providers
    - Compatibility of NEXCOM Vocoders with current FAA ground infrastructure (Voice Switching Control System) VSCS
5. Development of directional VHF Antennas

2.2.3 Spectrum Availability for Increased Data Traffic

Ka-band satellite service offers increased link capacity of at least two orders of magnitude over the current and near term VHF data links (approximately 10Kbps now to at least 1 Mbps over Ka-Band). We believe commercial service providers will apply Ka-band technology to the cabin passenger services and this represents an opportunity for leveraging the technology for delivery of broadcast FIS and TIS data to all classes of aircraft. Eventually two-way satellite communication will support request reply applications. Satellite delivery of FIS and TIS data is not in the NAS 4.0 Architecture.

A major technology focus for generation-after-next broadband satellite communications services (deployed in the 2003-to-2010 timeframe) is on the need to provide more bandwidth, i.e., a focus on Ka-band (30/20 GHz) and the 50/40 GHz band.

The need exists for higher efficiency transmitters, more adaptive bandwidth versus power efficient modulation, forward error correction coding and much expanded use of the variable bit rate formats of dynamic multiplexing techniques such as Asynchronous Transfer Mode (ATM) based technologies.

User Needs Impacted:

The use of Ka-band technology requires improvements in antenna and receiver technology to support the wide range of aviation users and aircraft types. Interface standards must be determined.

Summary of Solution Candidates:

The following solution candidates are discussed in more detail in Task 11.

- Development of low cost, stabilized, steerable Ka-band antennas suitable for all aircraft
- Development of Ka-band transceivers suitable for aeromobile use
- Multimode Radio with Ka-band Interface
- SATCOM aeromobile Standards.

2.2.4 Traffic Information System Definition

The NAS architecture indicates that local vicinity traffic information will be gathered on the ground and provided to aircraft via a data link. The data link is not specified and the interface to the TIS is not defined. Communications requirements such as volume of data, data formats, data integrity, and domains for distribution (i.e. within TRACON, ARTCC, or sector) have not been defined. The timeliness of TIS information is estimated at 10 seconds from target aircraft location, through the ground processing and uplink to the receiving aircraft for display. Ground processing will be required to fuse the data from numerous sources and reduce the information transmitted to the aircraft.

User Needs Impacted:

- Pilot situational awareness of traffic
- Loss of pilot aid for locating other aircraft in VFR conditions
- Support for self-separation concepts.

Summary of Solution Candidates:

The following issues are discussed in more detail in Task 11:

The proposed solution for TIS is satellite broadcast. The information does not require acknowledgement, does not have low latency requirements, is constantly changing, and is needed by all users in the NAS. In the absence of a broadcast satellite link, VHF links may provide the service if the data can be constrained to the data rates of proposed links.

2.2.5 Cross-Cutting Technology Issues

Cross-cutting technology gaps are issues that are transmission media independent and that effect multiple service areas

2.2.5.1 NAS-Wide Information System Definition

Users have expressed the need for increased flexibility, along with operating efficiencies and increased levels of capacity and safety in order to meet the growing demand for air transportation. These needs are further characterized by: (1) removal of constraints and restrictions to flight operations, (2) better exchange of information and collaborative decision making among users and service providers, (3) more efficient management of airspace and airport resources, and (4) tools and models to aid air traffic service providers.

The ability to meet these needs will hinge on the development of a NAS-wide information system. The NAS-wide information system is a core technology that enables the access and exchange of information among all participating NAS users. The result is a virtual information base that provides common situational awareness to all users who choose to participate. This information base also provides the foundation for efficient collaboration among users.

The challenge in maintaining the information base is to keep the dynamic data current for all participating users so that optimum decisions can be made. From a communications architecture point of view, an optimum design can only be achieved through the development of a standardized communications interface, data set, and access protocols. Other considerations include data refresh rates and communications performance parameters. These decisions must be made in conjunction with accurate simulation of the NWIS concept in a representative environment

User Needs Impacted:

NWIS is not yet defined. The users needs, however, are centered around the efficient access and exchange of information among all participants. Failure to implement the NWIS will have an adverse impact on the ability to maintain an information base that supports the ability to make efficient decisions that ultimately affect the capacity of the NAS.

Summary of Solution Candidates:

The NAS-wide Information System is pivotal for meeting the capacity and safety needs of the aviation community. If provides the foundation for common situational awareness and enables collaborative decisions. It is also essential that an efficient interface is developed between NWIS and the CSA that incorporates common data definitions and standard protocols. These issues are discussed in more detail in Task 11.

2.2.5.2 Information Security

Current aeronautical voice and data services do not typically employ security techniques. ATC commands and AOC air/ground data are transmitted without encryption and can be received by anyone suitably equipped. The change to greater dependence on data makes ATC communications more vulnerable to security threats unless appropriate security measures are taken. AOC users are expected to employ security techniques to ensure reliable service and maintain company proprietary data.

User Needs Impacted

The items below include security-related functional communications requirements contained in the User Requirements Database:

- A Security Management Program shall be an integral part of the design, manufacture, test, installation, operation and maintenance of a data link system.
- The Security Management Program shall identify the means of containing the effects of security breaches internally and externally to the data link system, identify recovery actions and also identify mitigation procedures to prevent re-occurrence.
- A security policy shall be developed for data link systems.

- The data link system shall be protected against security violations in accordance with performance requirements as described in the service descriptions.
- The airborne and ground systems shall be able to detect security breaches and alert the users with appropriate data security warnings.
- Ground databases and recordings of data communications shall be protected against access by unauthorized persons.
- The system shall be secured from outside tampering.

Summary of Solution Candidates:

The following issues are discussed in more detail in Task 11:

Authentication, source validation, data privacy, and prevention of deliberate interference are issues that have become increasingly troublesome for all communications service providers. The Research and development in the information security area by commercial service providers and by EUROCONTROL should be conducted and appropriate measures developed for use in the NAS.

2.3 Summary of Gaps by Segment

The tables below list the gaps by ground, air and space segment and indicates whether the gap is a system or component level gap. This report (Task 10) is directly tied to the solution candidate and areas for research and development discussed in Task 11. It is also closely aligned with the transition discussions in Task 8.

Table 2.3-1. Communications Technology Gaps by Segment

Architecture Requirement	*Communications Technology Gap Areas*	System or Component	Segment		
2007/2015			Ground	Air	Space
2007	**Advanced Aircraft Information System**	New System Required			
	High Speed Network (Flight Deck/Cabin)	Improved Component		x	
	Server	Improved Component		x	
	Multifunctional Displays	Improved Component		x	
	Intelligent Router	Improved Component		x	
2007	**VHF Improvements**				
	Directional VHF Antennas	Improved Component		x	
	Modulation	Improved System	x		
	Virtual Network	Improved System	x		
	Compression	Improved Technology	x		
	Voice synthesis	Data Link	x		
2007	**SATCOM**	New System, Component and Datalink Required			
	Multi-mode Radio with Ka-band Interface	Improved Component		x	
	Development of efficient modulation techniques for Ka satellite bands	Improved Component		x	x
	Mobile Standards	Improved System			x
	Ka-band Receiver Improvements	Improved Component		x	

Architecture Requirement	*Communications Technology Gap Areas*	System or Component	Segment		
2007/2015			Ground	Air	Space
	Ka-band Antenna Improvements	Improved Component		x	
2015	**Traffic Information System**	New System Required			
	Com. Interface to TIS (standard data set, access protocol, user verification)	New System	x	x	

Table 2.3-2. Cross-Cutting Technology Issues

Architecture Requirement	*Cross-Cutting Technology Issues*	System or Component	Segment		
2007/2015			Ground	Air	Space
2015	**NAS-Wide Information System**	New System Required			
	Com. Interface to Distributed NAS Wide Database (standard data set, access protocol, user verification)	New System	x	x	
2007	**Information Security**	Improved Datalink Required			
	Authentication	New System	x	x	
	Data Validation	Improved System	x	x	
	Protection from Interference	Improved System	x	x	x

3 Acronyms

Term	*Meaning*
AAC	Airline Administrative Control
AATT	Advanced Air Transportation Technologies
AAIS	Advanced Aircraft Information System
AMSRS	Aeronautical Mobile Satellite (Route) Service
AOC	Airline Operational Control
ARINC	Aeronautical Radio Inc.
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
AWIN	Aviation Weather Information
BER	Bit Error Rate
COTS	Commercial Off-The-Shelf
EMC	Electromagnetic Capability
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
FEC	Frame error check
FOQA	Flight Operational Quality Assurance
FMS	Flight Management System
FSS	Fixed Satellite Service
GA	General Aviation
GPS	Global Positioning System
G/T	Gain to System Noise Temperature Ratio
HF	High Frequency
IFE	In-Flight Entertainment
IFR	Instrument Flight Rules
IP	Internet Protocol
LAN	Local Area Network
MFD	Multifunctional Display
NAS	National Airspace System
PSK	Phase Shift Keying
QAM	Quadrature Modulation
QoS	Quality of Service
RF	Radio Frequency
SAIC	Science Applications International Corporation

SATCOM	Satellite Communications
SOW	Statement of Work
SSR	Secondary Surveillance Radar
VHF	Very High Frequency
WAN	Wide Area Network